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# Phosphorus indexing for cropland: Overview and basic concepts of the Iowa phosphorus index

A.P. Mallarino, B.M. Stewart, J.L. Baker, J.D. Downing, and J.E. Sawyer

**ABSTRACT:** Excessive phosphorus (P) loss from soils impairs surface water resources. An assessment tool or index has been proposed to identify fields with high potential risk of P delivery. The P index integrates P source and transport factors into a decision making process that may lead to changes in current P management and soil conservation practices. The index recognizes that a single soil P threshold alone is not an appropriate evaluation factor because of the varying conditions across fields. Although most indices being developed in the United States include similar factors, source and transport characteristics are considered in various ways to best address the variable conditions across regions. The Iowa P index reflects conditions that predominate under grain-crop production systems, considers source factors in a multiplicative manner within three main transport mechanisms, and approximates loads of P likely to enter and become available to aquatic ecosystems. An erosional component considers sheet and rill erosion, P enrichment, total soil P, buffers, sediment delivery, distance to a stream, and the long term biotic availability of particulate P in lake ecosystems. A runoff component considers water runoff based on a modification of the runoff curve number (RCN), soil-test P (STP), rate, time, and method of P application. An internal drainage component considers the presence of tiles, water flow to tile lines, subsurface recharge from subsurface flow, and soil-test P. When the erosion risk is high, the index weighs particulate P loss heavily compared with dissolved P loss, and emphasizes long-term processes comparatively more than short-term processes. This P assessment tool helps identify alternative P and soil conservation management options for reducing total P delivery from fields to surface water resources.

**Keywords:** Phosphorus, phosphorus assessment tool, phosphorus index, phosphorus management, phosphorus risk index

## An increasing concentration of animal production in certain areas of Iowa and other states has led to increased application of manure to agricultural fields.

Often, the manure is applied at frequencies and rates that exceed the phosphorus (P) required to optimize crop yield or to offset P removal in harvested plant parts. Animal manure can supply the nitrogen (N) and P needed by crops as well as other nutrients. Due to its relative N and P contents and potential N losses, however, continued use of manure rates that supply the N removed in harvested grain or forage usually results in excess P application. Phosphorus application in excess of crop needs may increase P losses from fields and the potential for eutrophica-

tion of surface water resources. Eutrophication occurs when high nutrient levels in water result in excessive algae growth, which may reduce oxygen levels in water during decomposition. Phosphorus usually is the nutrient that limits and controls algae growth in freshwater bodies (Schindler 1977; Correll 1998). Increased nutrient supply to freshwaters has been associated with algal blooms, imbalances in water ecosystems, fish kills, increase in toxin-producing microorganisms, and reduced aesthetic value of lakes or streams. The potential problem of excessive P loss from agricultural fields is compounded because soil-test summaries show that more than 60% of the soils of Iowa and other regions already have soil-test P (STP) levels

higher than needed to optimize crop production (Fixen 2001). The upper limit for P that should be applied to fields with minimal P loss to water resources could be ultimately determined by the P level in the topsoil and the potential for P delivery through erosion, runoff, or subsurface drainage. Thus, better estimates of the potential for P loss from agricultural soils are required, especially for manured soils.

In April 1999, the U.S. Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS) issued a national policy and general guidelines on nutrient management. These guidelines apply to nutrient management where nutrients are applied to the land, including organic by-products and animal manure. The national policy and guidelines suggested the use of one of three P risk assessment tools: agronomic STP interpretation classes, environmental soil P threshold limits, or a P assessment tool (or P index). Even before this NRCS national policy was adopted, states began developing P-based nutrient management guidelines or regulations that affect a greater proportion of crop and animal producers.

The STP level and the P application rate are the most frequently mentioned factors for both estimating P delivery to surface water and as the subject of regulation. Using only these two factors as tools to predict P loss from soils and P transport to surface water resources seriously limits the accuracy of the estimates. A specific STP value or rate of P application may have a markedly different impact on P delivery from fields having different soil properties, landforms, and management. Phosphorus delivery to water bodies is affected by the factors that influence soil erosion and water flow. Thus, the P index approach is more comprehensive than relying only on a soil P threshold value since it provides the means for identifying fields that have high potential for P delivery to surface water resources and the reasons for such a

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high potential loss. Additionally, the P index can be used to identify nutrient management practices that reduce these high P losses and that contribute to conserve soil and water quality.

### Characteristics of Phosphorus Indices

Most versions of P indices that have been or are being developed include a number of site characteristics related to the source, transport, and management of P. These characteristics (or factors) may include soil erosion potential, soil runoff class, STP, fertilizer or organic P application rate and method, as well as others. In early P index versions (Lemunyon and Gilbert 1993; USDA-NRCS 1994) each factor was assigned a relative potential P loss rating with a corresponding numerical value. Also, a weighting coefficient was assigned to each factor to reflect its relative importance in contributing to P loss (for example, 0.5 to 1.5). The P index was calculated by multiplying each potential P loss rating by its corresponding weighting factor and summing the results. The index value for an individual field was placed into a category (for example, very low to very high) with associated interpretations and recommendations for nutrient management. Later index versions developed for specific regions included other factors and changed how potential P loss ratings were calculated to obtain a P index. Additional factors included (or substituted for some of the factors mentioned above) distance to water body; tillage, vegetation, or grazing management; site hydrology (for example, slope gradient and length, flooding frequency, drainage class, subsurface drainage, etc.); and estimates of the degree of soil P saturation.

In early P index versions, the factors were additive. This means that all factors were considered equivalent (with adjustments for variable weighting) and there was no accounting for interaction among terms. A modification introduced in recent indices (i.e., Gburek et al. 2000; Jokela 2000) uses a multiplicative approach. The various factors are arranged into two distinct groups: P transport factors (for example, soil erosion, runoff class, and distance to a stream) and P source factors (STP, P rate, and application method of both fertilizer and organic P sources). The P transport factors receive rating values of less than one, and are multiplied together to yield an overall P transport potential with a value between zero and one. The P source potential value is then multiplied by the P transport

potential value. Thus, the P transport potential value serves as a scaling coefficient that reduces the full P source potential by an amount proportional to the P that is retained before reaching a stream.

### Rationale and Major Concepts of the Iowa Phosphorus Index

The Iowa P index (USDA-NRCS 2001b) uses a multiplicative approach to combine source and transport factors within three major components based on the major P transport mechanisms. These components are erosion (sediment loss), runoff (water loss), and subsurface drainage (water loss to surface water resources through tiles or coarse subsoils or substrata). Each component provides an approximate (or proportional) estimate of the amounts of P delivered from fields through each transport mechanism that would be biologically available for aquatic ecosystems. The outputs from the three components are summed to get an overall approximation of the total biologically-available P delivered. The resulting number (one per field or per each conservation management unit within a field) is placed into one of five risk classes (very low to very high). These classes are based on current knowledge concerning the impact of P loads on eutrophication of water resources.

Major advantages of earlier approaches to P indexing are that they produced simple indexes and did not require (although may have included) assumptions concerning functional relationships between all source and transport factors and estimates of amounts of P delivered from fields. But these earlier approaches did have their limitations. For one, they could not achieve their full potential to integrate an understanding and description of the basic processes with the mechanics of the index calculations and the risk ratings. Secondly, and perhaps most importantly, they did not consider estimates of P delivery, which complicated the comparison (or normalization) of different indices developed for various regions. The Iowa index alleviates these limitations of the earlier approaches. It attempts to link the index output to the processes controlling P delivery from fields by integrating the different processes into a quantitative set of components that directly relate to estimates of P loads that affect eutrophication of surface water resources. Indices that integrate estimates of P delivery from fields with a risk

index can be reasonably normalized across regions. One limitation of the approach used by the Iowa P index is that current knowledge only enables a fragmentary estimate of effective P loads, and a complete modeling of P transport is not possible. The main characteristics and concepts of the Iowa P index are based on current knowledge about the processes that contribute to P delivery to surface waters, recognition of the predominance in Iowa of tilled cropland compared with other land uses, and determination that soil erosion is a major P transport mechanism. The index is based on current research data, survey results, and scientific judgment when the data are not yet available.

The Iowa P index utilizes common tools used by the NRCS field staff to estimate the impact of landscape forms, soil types, and management practices on soil and water loss from fields. Some of these tools have been modified to better estimate losses for the most representative area of individual agricultural fields. Thus, the index uses existing information available through producers and NRCS field offices for soil classification, landscape forms, and major soil physical properties; the Revised Universal Soil Loss Equation (RUSLE) to estimate sediment loss through sheet, rill, and ephemeral gully erosion; sediment delivery ratio (SDR) and sediment trap efficiency of soil conservation practices to estimate sediment delivery off fields; runoff curve numbers (RCNs) to estimate water runoff; and county historical precipitation data. In contrast to some other indices, the Iowa P index does not require producers to collect complicated field measurements such as slope gradient and length that are available to NRCS field office staff from existing digitized soil survey databases. Other than field location and soil and crop management information needed to estimate gross erosion from RUSLE and RCNs, it requires only a recent soil-test P value and the distance from the center of the field to the nearest perennial or intermittent stream.

The Iowa P index reflects the concept that erosion from cropland is a major source of P loads to surface water resources in Iowa and that sediment-bound P is biologically active in Iowa aquatic systems. Because P is strongly adsorbed to soil particles, P associated with eroded soil particles is the primary form of P entering surface waters through erosion from cropland (Vaithyanathan and Correll 1992). Major characteristics of Iowa crop and animal

production systems include a predominance of row-crop production, chisel-plow tillage, confined swine and beef production systems, and manure application mainly to cropland. Thus, the index weighs particulate P losses heavily when the erosion risk is high. Dissolved P is readily available to aquatic organisms, whereas a large proportion of the particulate P will be released to the water over a variable period of time. Aquatic research demonstrates that a large proportion of the particulate P can be made available through chemical, biological, and hydrological processes (Sonzogni et al. 1982; Hartikainen et al. 1996; Sondergaard et al. 1996; Gonsiorczyk et al. 1998; Rydin 2000). Iowa scientists involved in studying P transport processes and water quality believe early indices have under-emphasized the long term impact of particulate P losses on lake ecosystems, especially for conditions such as those in relatively shallow natural glacial-derived lakes or artificial reservoirs predominant in Iowa. But this influence is difficult to predict because it depends on many factors such as water body chemistry, depth, input and output patterns, and usage (recreation, motorized boats, etc.).

Partly due to this long term approach, the index does not differentiate between commonly used P sources and gives similar weight to fertilizer, manure, and other organic sources. Differences in water solubility of the P in some organic sources may influence the short term impact of P application on P loss through runoff or subsurface flow (Kuykendall et al. 1999; Eghball and Gilley 1999). Dissolved P in runoff or subsurface flow immediately after solid manure (especially mixed with bedding) or compost application may be lower than for other manure sources (such as liquid swine manure or poultry manure) because solid manure often has a lower proportion of water soluble P. On the other hand, losses of soluble P in runoff may be lower for liquid manure than for solid manure because of greater infiltration and soil interaction when liquid manure is applied. High solubility of manure P applied to pastures or forested land increases the risk of dissolved P loss with runoff (Sauer et al. 2000). But this loss may not necessarily be substantiated when long-term losses (one or more years) and total P delivered with eroded sediment from cropland are considered.

## Components and Factors of the Iowa Phosphorus Index

**Erosion component.** The output of the erosion component is an approximate (proportional) estimate of the total amount of P delivered with sediment (in lb P/ac/yr), excluding dissolved P in runoff, that is likely to become available to aquatic ecosystems. Estimates of soil loss through sheet and rill, ephemeral, and classic gully erosion are modified by considering the SDR and conservation practices such as sediment traps and vegetative buffers. Furthermore, approximate P loads are estimated by considering total soil P, the impacts of landform and management on sediment P enrichment, and the proportion of particulate P likely to become available for aquatic organisms.

Gross erosion is estimated using the NRCS Field Office Technical Guide (USDA-NRCS 2001a) to calculate the t/ac/yr of soil loss through sheet and rill erosion with RUSLE (Section I, Erosion Prediction) plus ephemeral and classical gully erosion (Section I, C-3, Gully Erosion). The SDR is derived from a modification of existing procedures in use by NRCS (USDA-NRCS 2001a, Section I, Erosion and Sediment Delivery) to estimate sediment delivery for watersheds based on area. The modification allows the use of the basic SDR concept to estimate sediment delivery for individual fields by transforming area to linear distance from the center of the field to the nearest perennial or intermittent stream down the slope by means of the following equation:

$$\text{Distance} = 0.7 \times \text{Area}^{0.6} \quad (1)$$

The equation was derived from one developed by Linsley et al. (1982) to relate watershed length (mi) to area (sq mi) where the basins tend to elongate as they grow larger. In our case, we are considering the distance to the center of the field, so the original coefficient of 1.4 was divided by 2. When the field does not outlet directly to a stream, it is assumed that the sediment delivery for a field "centered" in a watershed is the same as for the watershed as a whole. A support chart included with the index summarizes output SDR values for four major Iowa landform regions. The output values from the chart are unitless, and range from 0.03 to 1.0 to account for situations when little of the eroded soil reaches the stream to situations

when all of it likely reaches the stream. Another support chart provides coefficients for the sediment trap efficiency of specific conservation practices such as level terraces, ponds, and others, which can reduce the sediment delivery to a field edge by 80 to 100% according to NRCS standards.

The buffer factor refers to a vegetative buffer that meets NRCS standards for filter strips (USDA-NRCS 2001a, Section IV, Standards and Specifications). A support table included with the index provides values for three classes arranged by buffer widths that range from 0 to 22.9 m (0 to 75 ft) or wider. The classes were based on published research (Bingham et al. 1980; Dillaha et al. 1989; Magget et al. 1989; Robinson et al. 1996) and current Iowa research (Baker ongoing). The output values from the chart are unitless. Values range from 0.5 to 1.0 to account for situations when the buffer is most effective in retaining sediment to situations in which the buffer does not exist or is insufficient and all the sediment leaves the field.

An enrichment factor accounts for the increase in the proportion of finer or less dense soil particles contained in eroded sediment, which tends to have a higher concentration of P when certain land treatments are present (Menzel 1980; Sharpley 1985). Five classes of enrichment coefficients varying by tillage system, grain or forage crops, and presence or absence of a buffer strip at least 6.1 m (20 ft) in width are shown in a support table included with the index. The output values from the chart are unitless. Values range from 1.1 for situations in which little enrichment is expected (without a buffer and with tillage) to 1.3 for situations in which enrichment is the highest (with a buffer and no-till management or forages). These values were determined after studying published research and obtaining values for various scenarios using the water erosion prediction project (WEPP) model (Menzel 1980; Sharpley 1985; Lafen et al. 1997; Baker et al. 2001).

The total P factor is based on an estimate of the total P concentration of the surface 15.2 cm (6 in) layer of soil and the fraction that may become available to aquatic organisms. Total soil P is calculated from the average amount of total P in low P testing soils and the increase in total P due to application of fertilizers or manure estimated from a recent measurement of STP:

$$\text{Total P} = 500 + (3.0 \times \text{STP}) \quad (2)$$



The average value of total soil P in the surface 15.2 cm (6 in) layer of low-testing Iowa soils is 500 mg kg<sup>-1</sup> (500 ppm) (Fenton 1966; Allen and Mallarino 2001). The 3.0 coefficient in Eq. 2 reflects that in the long-term, a 1 mg kg<sup>-1</sup> (1 ppm) increase in STP measured with the Bray-P<sub>1</sub> or Mehlich-3 P corresponds to an increase in total soil P of approximately 3 mg kg<sup>-1</sup> (3 ppm) (Barber 1979; Allen and Mallarino 2001). When the Olsen test is used, the soil-test value is divided by 0.6 to account for the known lower P extraction with this test (Mallarino 1997). In addition, total P is multiplied by a 0.7 coefficient to reflect that on average only approximately 70% of the particulate P delivered to a lake will be biologically available within a long but reasonable time period for algae growth (Hartikainen et al. 1996; Sondergaard et al. 1996; Gonsiorczyk et al. 1998; Rydin 2000).

**Runoff component.** This component estimates the amount of total dissolved P delivered with water runoff (lb P/ac/yr). The estimate of dissolved P includes dissolved orthophosphate P (often referred to as dissolved reactive P) and other dissolved P fractions. Runoff P is estimated by the use of RCNs, historic annual county precipitation data, an equation that estimates the impact of recent P application on STP, an equation that estimates the impact of STP on the concentration of dissolved P, and the impact of the timing and method of P application on the concentration of dissolved P in runoff.

The RCNs term in the runoff component expresses runoff volume as a fraction of the average annual precipitation for each county. Users select fraction values from support charts that include RCNs and county precipitation data. Runoff curve numbers were developed by NRCS with consideration of precipitation intensity, soil hydrologic group, vegetative cover, and other factors (USDA-NRCS 1989). The procedures used to adapt the RCN approach for individual rainfall events in order to predict average annual surface runoff can be summarized in two steps. First, the relationship between rainfall and runoff were evaluated for several RCNs to determine the amount of rainfall for which there is no runoff. Based on this analysis, we decided to use 1.9 cm (0.75 in) of rainfall as the limit below which no runoff would be produced. Then precipitation data from nine weather stations throughout Iowa were statistically analyzed to determine average annual precipitation for each station and the percent-

age of that precipitation that fell in events with less than 1.9 cm (0.75 in). For all stations, we found that about 50% of the precipitation occurs in events that would not generate runoff. Second, 24 h storm events were evaluated for recurrence intervals of 1, 2, 5, 10, 25, and 50 years. Runoff was calculated for each of these events for RCN values of 50, 60, 70, 80, 90, and 95. The percent of runoff was then computed for each condition, and a weighting procedure was used to determine the weighted average percent of runoff for each RCN. For use in the P index, this number is then multiplied by 0.5 (to account for the observation that approximately 50% of the rainfall does not produce significant runoff). Also, to determine the "runoff factor" in the P index, the average annual precipitation for each county is divided by the number 4.415 to convert inches of rain to millions of pounds of water per acre.

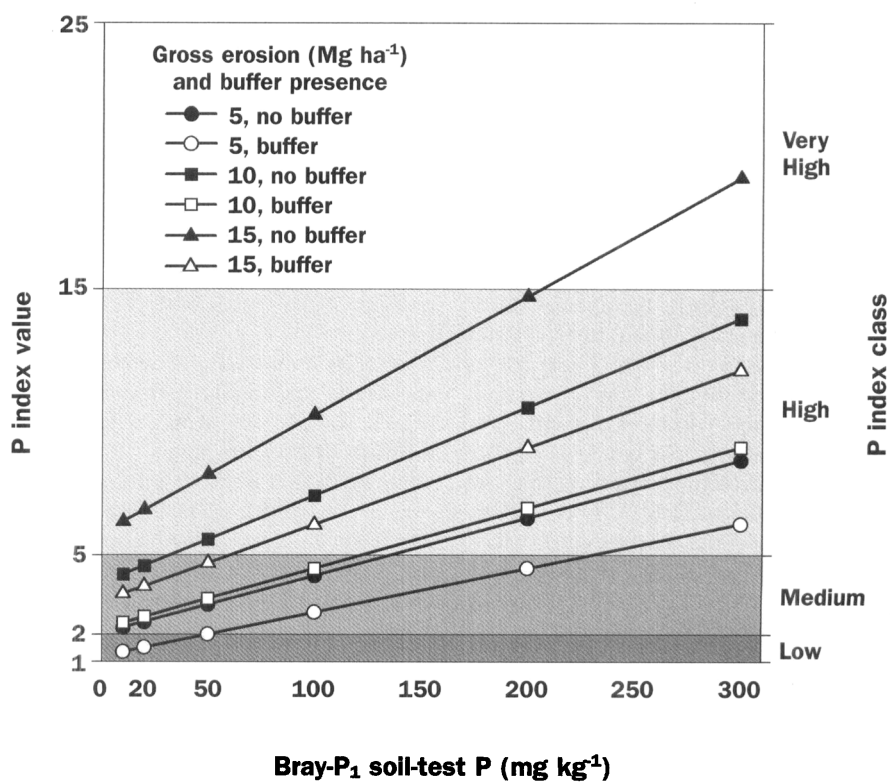
The STP runoff factor estimates the total dissolved P concentration in water runoff, assuming a linear relationship between P concentration in runoff and STP. The index requires only soil P tests and sampling procedures currently recommended for crop production in Iowa. Iowa State University supports the Bray-P<sub>1</sub>, Mehlich-3, and Olsen P tests, and the recommended soil sampling depth for all tillage systems is 15.2 cm (6 in) (Voss et al. 1999). The linear relationship between STP and dissolved P is described by the following equation:

$$\text{Dissolved P} = 0.05 + (\text{STP} \times 0.005) \quad (3)$$

The coefficients in this equation represent averages derived after studying both unpublished and published relationships for soils of Iowa (Klatt et al. 2000; Klatt 2001; Mallarino et al. 2001) and other regions (Sharpley 1995; Pote et al. 1996; Pote et al. 1999). Although in

**Figure 1**

Effect of soil-test phosphorus, gross erosion, and buffer strips on phosphorus index values for a hypothetical field in South Central Iowa. The assumed buffer width was 75 feet and the assumed distance from the center of the field to the nearest perennial or intermittent stream was 1000 feet. To simplify the interpretation of the data, values for other factors were maintained constant to reflect typical values for Iowa.



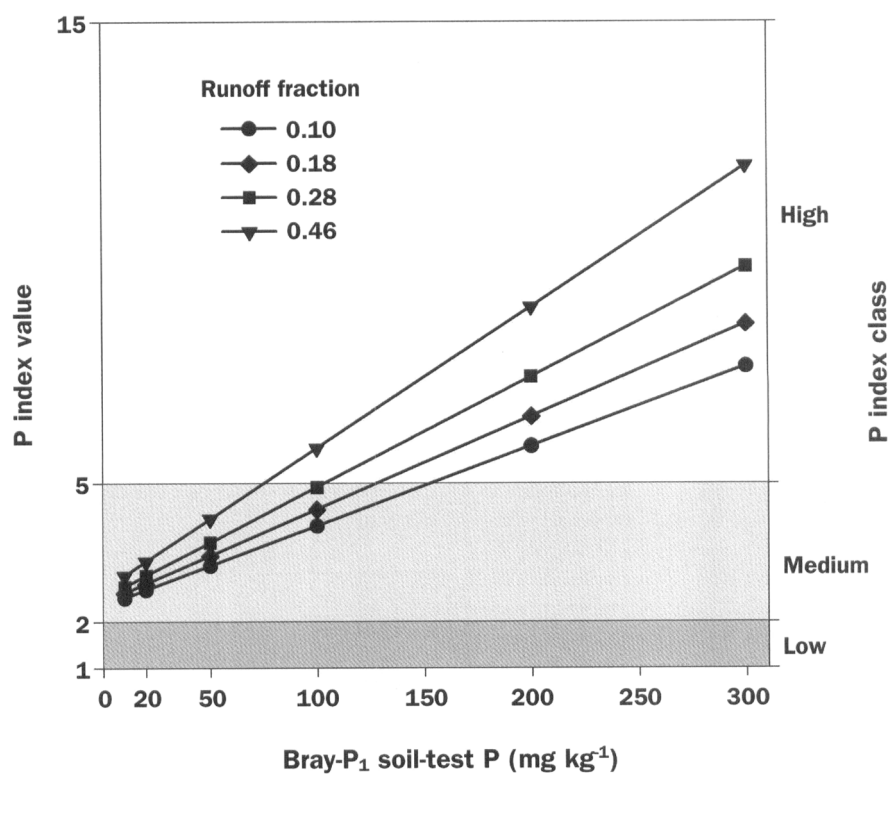
some instances the relationship was described as curvilinear, with dissolved P concentrations increasing faster at high soil P levels, the curvilinear trends were not statistically better than linear trends or resulted in only small improvements in the coefficients of determination.

The STP value in equation 3 corresponds to samples collected to a depth of 15.2 cm (6 in) when the Bray-P<sub>1</sub> and Mehlich-3 tests are used. When the Olsen test is used, the soil-test value is divided by 0.6 to account for the lower P extraction. The 0.05 coefficient is the intercept of the equation and represents the concentration of total dissolved P in runoff at very low STP levels. This reflects the common finding that the intercept of the lines was seldom equal to zero and suggests the presence of dissolved P in runoff even at very low STP levels. The 0.005 coefficient is the slope of that relationship: the average increase in dissolved P per unit of STP.

The basic underlying concept for using agronomic tests and soil sampling procedures is that available research does not clearly support the need for a change to other soil testing procedures (extractant, sample depth, or sampling strategies) for Iowa cropland. Ongoing Iowa research suggests that testing procedures aimed mainly at environmental P evaluations, such as the iron (Fe)-oxide impregnated paper test (Menon et al. 1989) and water extractable P (Pote et al. 1996), may extract different amounts of P but are closely correlated with P extracted by current agronomic testing procedures over a wide range of conditions (Mallarino et al. 1998; Klatt et al. 2000; Klatt 2001; Mallarino et al. 2001). The concept of soil test field calibration used to develop interpretations for agronomic soil tests also applies when the main objective of soil testing is to estimate amounts of soil P that could potentially reach surface water supplies. Extensive calibration research is being conducted in Iowa and other states. Ongoing Iowa research shows that agronomic and environmental tests similarly correlate P loss with runoff or subsurface drainage (Klatt et al. 2000; Klatt 2001; Klatt et al. 2001; Mallarino et al. 2001). These studies, which included STP values (Bray-P<sub>1</sub> or Mehlich-3 P) as high as 600 mg kg<sup>-1</sup> (600 ppm) in the surface 15.2 cm (6 in) of soil, did not provide conclusive support for other research (Jokela et al. 1998; Jokela 2000) suggesting that use of P saturation indices may improve relationships between STP and dissolved P in runoff.

**Figure 2**

Effect of soil-test phosphorus and water runoff volume on phosphorus index values for a hypothetical field in South Central Iowa. The hypothetical field location was similar to the one used in Figure 1. To simplify the interpretation of the data, values for other factors were maintained constant to reflect typical values for Iowa.



Use of P saturation is expected to improve predictions of dissolved P loss at very high STP values.

The rate, method, and time of P application factor estimates the additional impact of recent P applications on STP since the last soil sampling and before growing a crop:

$$\text{Dissolved P} = ((P_2O_5/4.58) \times 0.5) \times \text{"Method and Time" factor} \times 0.005 \quad (4)$$

The P<sub>2</sub>O<sub>5</sub> term of Eq. 4 represents the P application rate (fertilizer, manure, or other organic sources). The 4.58 coefficient transforms lb of P<sub>2</sub>O<sub>5</sub> to ppm of P (elemental) assuming that a 15.2 cm (6 in) slice of topsoil over an area 0.405 ha (1 ac) in size weighs 907 Mg (1000 t). The 0.5 coefficient transforms this value into effective STP increase by assuming that 50% of applied P within 100 d after the application is measured by the Bray-P<sub>1</sub> or Mehlich-3 soil tests. This coefficient was derived from published (Koswara and Hanway 1969) and partial results from several ongoing Iowa research projects that included

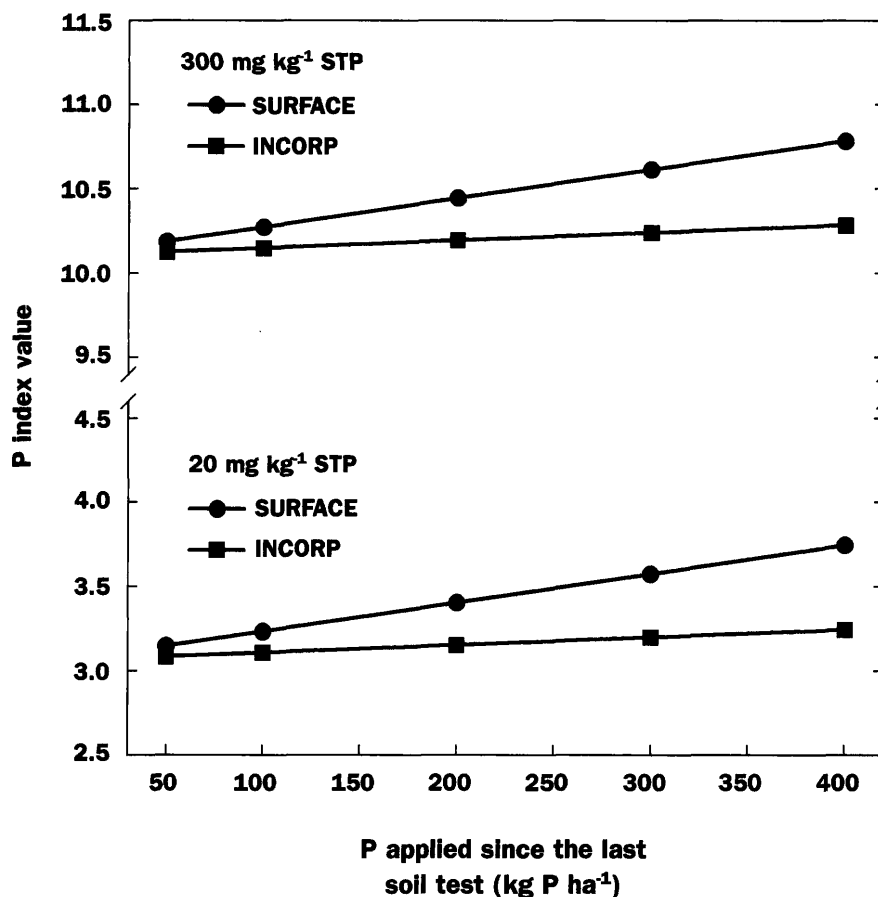
various soil series and P fertilizer applications.

Values for the method and time factor of the P application term are unitless and modify the impact of P applications on dissolved P with runoff. The values for four classes that consider methods and time of application are provided in a support table included with the index. Values range from 1.5 when P is surface-applied to snow covered or frozen ground, water saturated soil, or flood plains (full impact) to 0.4 when the P is injected into the soil or incorporated within 24 h of the application. These estimates were developed based on published research (Hensler et al. 1970; Long et al. 1975; Young and Mutchler 1976; Long 1979; Schulte et al. 1979; Lorimor 1995) and current unpublished research (Baker and Mallarino, ongoing). The 0.005 coefficient represents the slope of the relationship between STP and the concentration of dissolved P in the runoff. The assumed soil bulk density value is within average observed values for the major agricultural soils in Iowa.

**Subsurface drainage component.** This com-

**Figure 3**

Effect of soil-test phosphorus and the rate, method, or time of phosphorus application since the last soil test on phosphorus index values for a hypothetical field in South Central Iowa (similar to the one used in Figures 1 and 2). INCORP = injected or incorporated within 24 hours; STP = soil-test phosphorus; and SURFACE = surface application to frozen, snow covered, or water saturated soils or to floodplain soils. To simplify the interpretation of the data, values for other factors were maintained constant to reflect typical values for Iowa.



ponent estimates the amount of total dissolved P delivered to surface water resources through flow to tile lines as well as subsurface recharge from subsurface flow. It uses existing databases (soil classification, landscape forms, and major soil physical properties), an estimate of water flow, historic county precipitation data, and an estimate of the impact of STP on the concentration of dissolved P in the subsurface water. The precipitation data are the same as those used for the runoff component.

The flow factor is determined by the presence or absence of subsurface flow. If tile or coarse-textured subsoils or substrata are known to be present, the flow factor takes a value of one (unitless). Otherwise it has a value of zero, and it is assumed that no P is delivered to surface water resources via this

transport mechanism. Results of ongoing research projects led by J. Baker suggest that approximately 10% of the average annual precipitation will flow through tile or coarse-textured subsoils or substrata, so a constant (average) value of 0.1 is included in the equation. If it is unknown whether tile or coarse-textured subsoil or substrata is or are present, tile is assumed to be present if the following qualifications are met: the field is cropped to grain crops, the predominant soil series of the field has 5% slope or less and 40% clay or less, and the soil is in the poor or very poor internal drainage class. A list of the soil map units that have these characteristics is provided in a support table included with the index. Another support table lists the soil map units with coarse-textured subsoil and/or substratum.

Available research data from Iowa do not support the use of a continuous relationship between soil P and dissolved P movement through soil profiles at this time (Baker et al. 1975; Johnson and Baker 1984; Klatt et al. 2000; Klatt 2001). But this research suggests that P loss increases with subsurface drainage at STP concentrations in the surface soil (15.2 cm or 6 in) higher than approximately 100 mg kg<sup>-1</sup> (100 ppm) by Bray-P<sub>1</sub> test and higher than 15% P saturation. The STP factor for this component has a value of 0.1 if Bray-P<sub>1</sub> or Mehlich-3 STP (or Olsen P divided by 0.6) is 100 mg kg<sup>-1</sup> (100 ppm) or less in the top 15.2 cm (6 in) of soil, which represents an average dissolved P concentration in the subsurface flow water of 0.1 mg kg<sup>-1</sup> (0.1 ppm). The factor value is 0.2 if STP is higher than 100 mg kg<sup>-1</sup> (100 ppm).

#### Phosphorus Delivery Risk Interpretation Classes

The sums of the partial index numbers for each component (erosion, runoff, and subsurface drainage) are classified into five risk classes. Data from published studies that estimated P loads to water bodies with varying degree of impairment (i.e., Canfield and Bachmann 1981; Downing et al. 2001) and data from ongoing Iowa watershed-scale studies (Downing and Kopaska 2000a, 2000b, 2001; Klatt 2001; Klatt et al. 2001) were used to establish the following classes:

1. Very Low (0-1). Soil conservation and P management practices have a small impact on surface water resources.

2. Low (1-2). The P delivery to water resources is greater than from a site with a very low rating, but current practices keep water quality impairment low.

3. Medium (2-5). The P delivery may produce some water quality impairment. Consideration should be given to future soil conservation or P management practices that do not increase the risk of larger P delivery.

4. High (5-15). The P delivery produces large water quality impairment. Remedial action is required. New soil and water conservation or P management practices are necessary to reduce off-site P movement.

5. Very High (higher than 15). Impacts on surface water resources are extreme. Remedial action is urgently required. Soil and water conservation practices plus a P management plan, which may require discontinuing P applications, must be implemented.

Data in Figures 1 to 3 illustrate the



sensitivity of the two most important P index components (erosion and runoff components) to various factors. Although the results are based on hypothetical scenarios, the values chosen represent values typical of Iowa cropland. Figure 1 shows that a specific STP value has a markedly different impact on index values, depending on erosion levels and the presence of a buffer strip. This striking difference appears because STP is used to estimate total soil P that can be transported through erosion. Figure 2 shows the impact of STP on index values for different runoff fractions. In the runoff component, STP and runoff fractions are two important factors used to estimate the loss of dissolved P through runoff. Other important factors of the runoff component are the P rate and the method or time of P application since the last soil sampling date. Data in Figure 3 and comparisons with data in Figures 1 and 2 suggest that the impact of the P rate and the method or time of application since the last soil test on index values is minor compared with the impacts of STP, erosion, and runoff volume. But the impact of long term P applications on index values is evaluated mainly by measuring STP, and this is one major reason for requiring a recent soil test. The scenarios in these figures show that the P index reflects the fact that erosion and runoff from cropland are major sources of P loads to surface water resources in Iowa and that sediment-bound P is biologically active in Iowa aquatic systems.

### Summary and Recommendations for Using the Iowa Phosphorus Index

The Iowa P index is a risk assessment tool that was developed to assess the potential for P delivery from fields to surface water resources. It considers P management and soil conservation practices that influence P delivery. The index does not include a built-in soil-test P or a P application limit. Instead, it provides information about the likely causes of high P delivery to surface water resources as well as useful information to help users choose from alternative P management and soil conservation practices that would reduce the risk of off-site P delivery. While the P index is intended to be used to assess the risk of P moving off a field to a water body, it can also be used to identify the critical parameters of soil, topography, and management that most influence that movement.

The P index is intended to be part of the planning process that takes place between the

land user and resource planner. It can be used to communicate the main concepts, processes, and expected results, of various alternatives in the management of a site's natural resources. It is not intended to be used as an evaluation scale for determining whether land users are abiding within water quality standards established by local, state, or federal agencies. The P index has been developed for local conditions on the basis of available Iowa research, information from other states that could apply to Iowa conditions, and from scientific judgment when research data were incomplete. This version of the index will be tested and modified periodically as new local research data become available.

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